Seismic performance evaluation of the Central Laboratory Universitas Andalas building with expansion joints

Fauzan [1*], *Geby* Aryo Agista[1], and *Zev* Al Jauhari[2]

[1]Department of Civil Engineering, Faculty of Engineering, Universitas Andalas, Indonesia
[2]Graduate School of Engineering, Toyohashi University of Technology, Japan

Abstract. The laboratory supports students' education and provides space for practice and research. One of the laboratories is the Central Laboratory Building of Universitas Andalas, located in Padang City, which has building expansion joints. Since Padang City is an earthquake-prone area, the planning of laboratory buildings must consider earthquake safety. An expansion joint is needed to ensure earthquake safety as a boundary for building structures. It is designed so that if a major earthquake occurs, the buildings are planned not to be damaged due to pounding so that potential losses can be minimized. This study evaluates the seismic performance of buildings with expansion joints based on the current Indonesian seismic codes. The study results show that the maximum displacement of the buildings (zones A, B, C, and D) does not exceed the distance between expansion joints. It prevents contact between them (pounding) during any seismic event, allowing the building to be declared safe during an earthquake. Additionally, the seismic performance of buildings complies with current Indonesian earthquake regulations, specifically regarding dynamic characteristics, inter-story drift, horizontal irregularity, and vertical irregularity.

1 Introduction

Padang City is prone to earthquakes, which have caused significant casualties in West Sumatra, Indonesia. This is due to its geographical location on the western coast of Sumatra Island, where there is a subduction zone and the meeting point of two tectonic plates, the Indo-Australian Plate and the Eurasian Plate [1]. Earthquakes result in various impacts, including material losses such as building damage and human lives lost. Efforts to reduce the risk of damage due to earthquakes need to consider the design and location of buildings, taking into account the characteristics of the earthquake and the local geology [2]. One way to ensure structural strength during an earthquake is to provide expansion joints in a tall and elongated building [3-5]. The design of the building's expansion joint system is very well used for buildings with elongated spans to avoid the domino effect from the earthquake load received. The vibrations caused by earthquake loads affect the behavior of building structures, especially in asymmetric buildings with T-shaped plans. Asymmetric buildings, where the center of gravity is not in the middle, can result in significant torsion when the building receives horizontal loads such as earthquake loads. Therefore, an evaluation of the building with expansion joints distance is necessary.

In recent years, many studies have been conducted on checking structural elements and evaluating building expansion joint distances, such as analyzing building structure expansion joint distances using a two-column dilatation system [6], analyzing expansion joint distances of L-layout buildings, and calculating reinforcement of beam and column elements around dilatation [7], Seismic performance and assessment of RC framed structure with geometric irregularities [8], building performance evaluation of A.N.S hotel building plan with and without dilatation in earthquake prone areas [9], Seismic performance evaluation of reinforced concrete building in Palu City [10]. One such building with expansion joints is the Central Laboratory Building of Universitas Andalas. This newly constructed building, inaugurated in 2023, is at the Universitas Andalas Campus, Limau Manis, Padang City, West Sumatra. It functions as the main laboratory facility at Universitas Andalas.

This study focused on evaluating the seismic performance of the central laboratory Universitas Andalas building plan with expansion joint according to the current Indonesian seismic codes, specifically regarding dynamic characteristics, inter-story drift, horizontal irregularity, and vertical irregularity.

2 Methodology

The Central Laboratory Building of Universitas Andalas is a support facility for students conducting practical activities and research. As shown in Fig. 1, the building is divided into zones A, B, C, and D.

In this study, seismic performance evaluation of building expansion joint is carried out by as-built drawing based on the current Indonesian seismic codes (SNI 1726:2019) [11] regarding the procedures for earthquake

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[*] Corresponding author: fauzan@eng.unand.ac.id

resistance planning for building and non-building structures (SNI 2847:2019) [12], and minimum load for planning of buildings and other structures (SNI 1727:2020) [13], regarding structural concrete requirements for buildings using ETABS software.

Fig. 1. The Central Laboratory Building of Universitas Andalas

2.1 Building data

This study analyzes three models: Model 1 is a 3D structural model of laboratory buildings Zones A and B, Model 2 is a 3D structural model of laboratory building Zone C, and Model 3 is a 3D structural model of laboratory building Zone D. Figs. 2 and 3 show a plan view of the central laboratory building and detail of expansion joints.

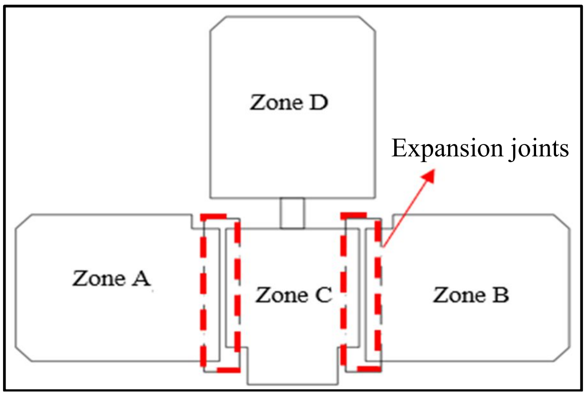

Fig. 2. Plan view of the Central Laboratory Building of Universitas Andalas

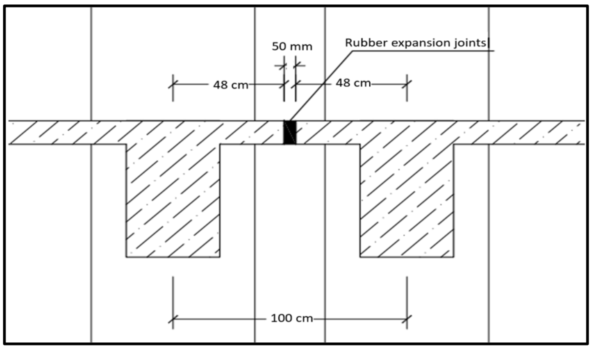

Fig. 3. Detail of building expansion joints

Table 1 shows the building data parameters used in the seismic performance evaluation of the Central Laboratory Building at Universitas Andalas. Based on the Detail Engineering Design (DED), the expansion joint between zones is 50 mm, as seen in Fig. 3.

Table 1. Building data of the laboratory building

Parameter	**Data**
Building Name	Central Laboratory of Universitas Andalas
Location	Limau Manis, Padang City, West Sumatra
Building Function	Laboratory
Number of Floors	3 Floors
Building Height	12 m
Expansion Joint Distance	50 mm

This study obtained the concrete quality, reinforcing steel quality, dimensions of structural elements, and room functions from as-built drawings. The compressive strength of the existing concrete is 24.9 MPa, as specified in the plan drawings, and the specified weight density for normal concrete is 2,400 kg/m^3. The reinforcing steel quality of the longitudinal bar is categorized as minimum yield strength (fy = 400 MPa), minimum tensile strength (fu = 560 MPa and the reinforcing steel quality of the ties bar is fy = 240 MPa, fu = 400 MPa. Steel bars' weight density and modulus of elasticity are 7,850 kg/m^3 and 2.10^5 MPa, respectively. The structure includes primary columns and beams with reinforcement bars, detailed in Tables 2 and 3.

Table 2. Details of columns

No.	**Type**	**Section**		**Flex. reinf. bar**	**Shear reinf. bar**	
		D	**W**		**S**	**M**
1	K1	700	700	20D22	Ø13-100	Ø13-150
2	K1-1	700	700	16D22	Ø13-100	Ø13-150
3	K2	Circle-500		12S150	Ø12-150	Ø12-150
4	K3	600	600	16D22	Ø13-100	Ø13-150
5	K4	500	500	12D22	Ø13-100	Ø13-150

Table 3. Details of beams

No.	**Type**	**Section**		**Flex bar**		**Shear reinf. bar**	
		D	**W**	**T**	**C**	**T**	**C**
1	S1	700	400	6D19	6D19	Ø10-100	Ø10-150
3	S2	500	300	5D16	5D16	Ø10-100	Ø10-150
4	B1	700	400	10D19	5D19	Ø10-100	Ø10-150
6	B2	700	400	10D19	5D19	Ø10-100	Ø10-150
7	B3	500	300	5D19	3D19	Ø10-100	Ø10-150
8	B4	400	300	5D16	3D16	Ø10-100	Ø10-150
9	B5	300	200	3D13	5D16	Ø10-100	Ø10-150
10	BS-1	500	300	5D19	3D19	Ø10-100	Ø10-150
11	B6	350	250	5D16	3D16	Ø10-100	Ø10-150
12	BD	350	250	5D16	3D16	Ø10-100	Ø10-150

2.2 Structural modeling

The 3D structural modeling of the Central Laboratory Building at Universitas Andalas using ETABS software. The structural elements, including floor slabs, were modeled as thin shells with rigid diaphragms, and columns and beams were modeled as frame elements with fixed support boundary conditions. The fixed support boundary condition restricts all translation degrees of freedom for the assigned entities to zero. It models portions of the geometry connected to a rigid body. This study uses these rigid bodies for ground foundations, column-foundation joints, and beam-column joints. The 3D structural model of laboratory building Zones A, B, C, and D is illustrated in Figs. 4-6.

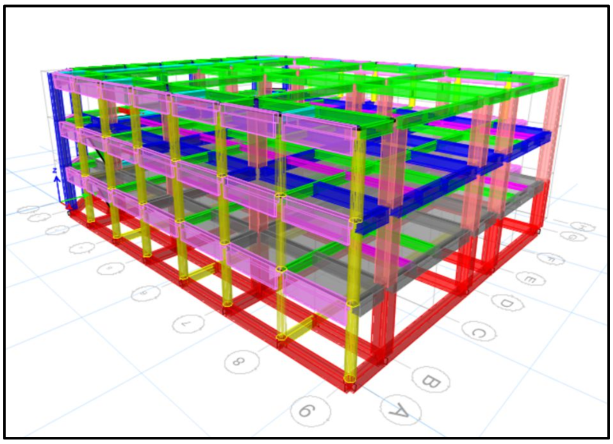

Fig. 4. 3D structural model of laboratory building zone A and B (model 1)

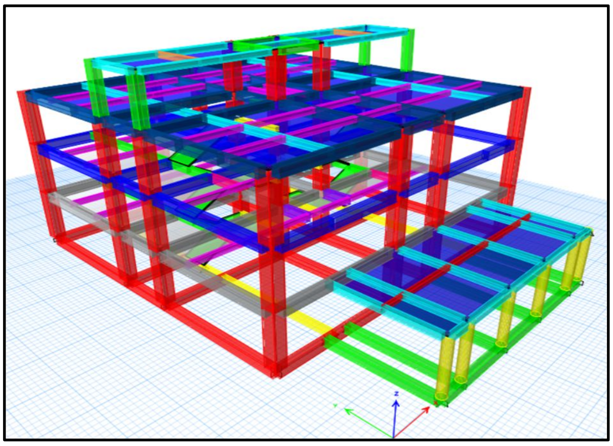

Fig. 5. 3D structural model of laboratory building zone C (model 2)

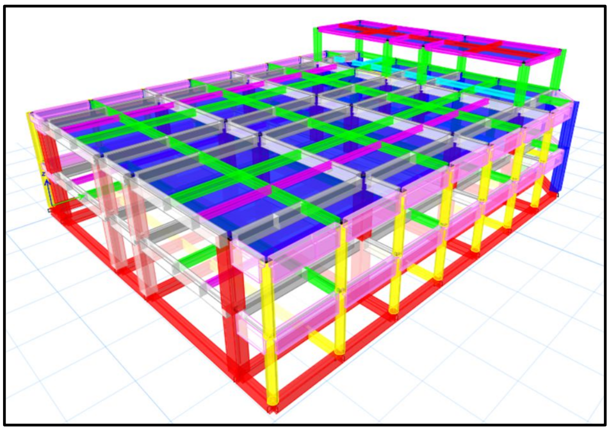

Fig. 6. 3D structural model of laboratory building zone D (model 3)

2.3 Loading analysis

2.3.1 Dead load

Based on SNI 1727:2020 [10], the dead load is the weight of all building construction materials installed in this model, including the weight of the beam itself and comprising walls, floors, roofs, ceilings, stairs, fixed partition walls, finishes, building cladding, as well as other architectural and structural components, and installed service equipment as additional dead load (Tables 4-6).

Table 4. Additional dead load for first and second floors

Type of load	Weight	Unit
Ceramic tile	24	kg/m^2
Spacing	20	kg/m^2
MEP	50	kg/m^2
Plafond	18	kg/m^2
Total	112	kg/m^2

Table 5. Additional dead load for roof floors

Type of load	Weight	Unit
Waterproofing	5	kg/m^2
Spacing	20	kg/m^2
MEP	50	kg/m^2
Plafond	18	kg/m^2
Total	93	kg/m^2

Table 6. Additional dead load for stairs

Type of load	Weight	Unit
Ceramic tile	24	kg/m^2
Spacing	20	kg/m^2
Total	44	kg/m^2

2.3.2 Live load

Based on SNI 1727:2020, live load is caused by users and occupants of the building, structures not including construction loads, and environmental loads such as earthquake loads. The minimum distributed live loads are listed in Table 7.

Table 7. Live load

Function	Weight	Unit
Floor system		
Office room	250	kg/m^2
Computer room	480	kg/m^2
Corridor	480	kg/m^2
Laboratory	400	kg/m^2
Toilet	250	kg/m^2
Roof deck	250	kg/m^2

2.3.3 Seismic load

A seismic load is an equivalent static load that acts on a building or part of a building that mimics the influence of ground movement due to the earthquake. In this study, the earthquake loads using parameters based on the Indonesian seismic standard (SNI 1726:2019) with shelter building as risk category IV, priority factor (Ie) 1.5, the value of the response modification coefficient (R) is 8, the over-strength factor system (Ω) is 3, and the deflection magnification factor (Cd) is 5.5, the approach reinforcement parameter (Ct) is 0.0466, and the approach period parameter (x) is 0.9. The acceleration spectrum parameters are used in the response spectrum design of West Pasaman District, Indonesia, as shown in Fig. 7.

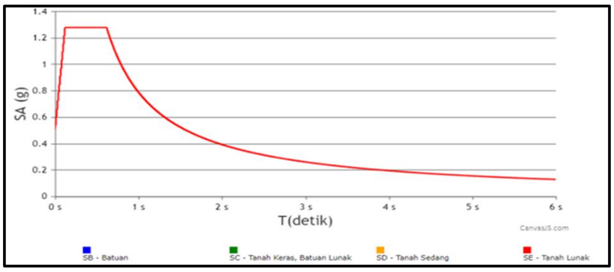

Fig. 7. Response spectrum of building's location

2.4 Load combinations

The load combinations are based on SNI 1726:2019 regarding the procedures for earthquake resistance planning for building and non-building structures, which are presented in Table 8. In ETABS, an envelope function in load combinations is used to determine the maximum and minimum values of response quantities (such as forces, moments, or displacements) from a set of load combinations. Instead of manually checking each load combination, an envelope automatically captures the extreme values (both positive and negative) across all the combinations included in the envelope.

Table 8. Additional dead load for stairs

No	Load combination	Note
1.	U = 1.4 D	Dead load
2.	U = 1.2 D + 1.6 L	Dead and live load
3.	U = 1.4 D + L ± 1.3 Ex ± 0.39 Ey	Dead, live, and earthquake loads
4.	U = 1.4 D + L ±0.39 Ex ±1.3 Ey	
5.	U = 0.7 D ±1.3 Ex ± 0.39 Ey	
6.	U = 0.7 D ± 0.39 Ex ± 1.3 Ey	
7.	Envelope	

3 Results and discussion

3.1 Evaluation of the existing building's expansion joints

The expansion joint distance evaluation was conducted on the Central Laboratory Building of Universitas Andalas in Zones A, B, C, and D by calculating the maximum building displacement, as shown in Figs. 8-10.

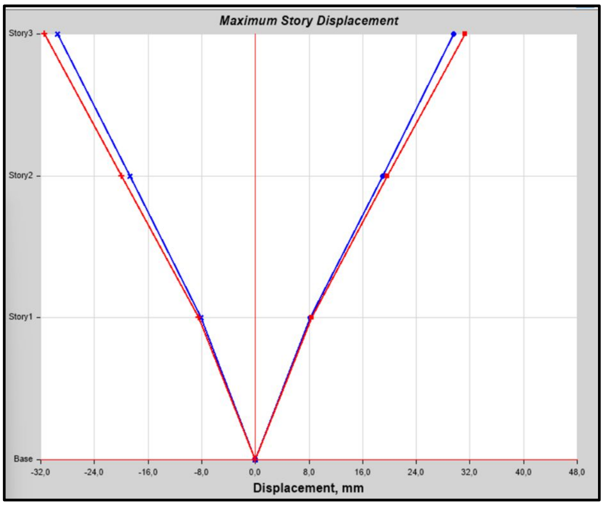

Fig. 8. Result of maximum displacement of model 1

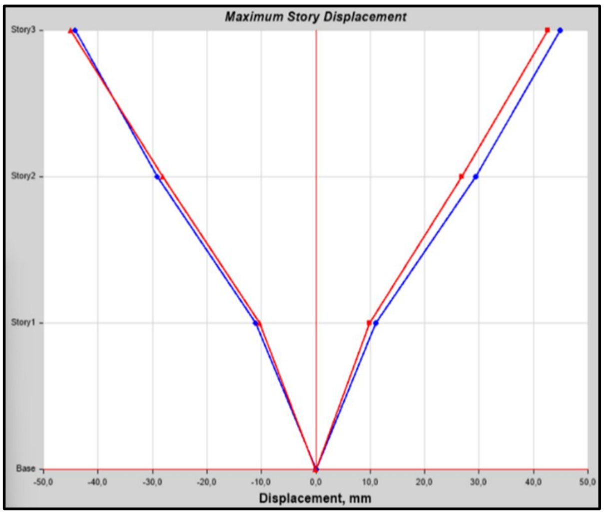

Fig. 9. Result of maximum displacement of model 2

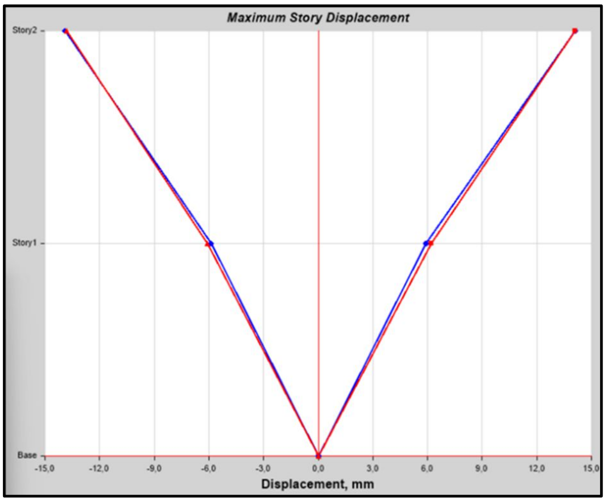

Fig. 10. Result of maximum displacement of model 3

Table 9. Maximum displacement of laboratory building

Zone of laboratory	Model	X-direction (mm)	Y-direction (mm)
A and B	1	29.253	31.221
C	2	44.880	42.662
D	3	14.110	14.098

Evaluation of the expansion joint distance was carried out on the Central Laboratory Building of Andalas University in Zone A and B with Zone C and Zone D with Zone C by calculating the maximum displacement of the building using the finite element method (FEM) of the ETABS computer program. The maximum value of the building displacement was obtained from the load combination envelope.

Table 9 shows the result of the maximum displacement in zones A, B, C, and D does not exceed the distance between expansion joints (50 mm), allowing the building to be declared safe in the event of an earthquake maximum (SNI 1726:2019). Therefore, the expansion joints distance in the building can be declared safe, and there will be no pounding during an earthquake.

3.2 Seismic performance of the laboratory building with expansion joints

3.2.1 Dynamic characteristic

Period T is a fundamental property in the structural design process, especially in earthquake-resistant structures. The vibration period of the structure will determine the magnitude of the earthquake load that will be applied in the structural design. A structure's natural vibration period depends on its mass and stiffness to vibrate freely without external forces. Based on the Indonesian National Standard SNI 1726:2019 article 7.8.2, the fundamental period of the structure (T) in the appropriate direction must be obtained using the structural properties and deformation characteristics of the elements in the structural analysis. The period of Model 1 is 0.433 seconds, Model 2 is 0.58 seconds, and Model 3 is 0.369 seconds. Both models have met the building planning requirements for the shape mode, namely shape modes 1, 2, and 3 experience translation in the x and y directions, and shape mode 3 experiences rotation.

3.2.2 Inter-story drift

The displacement that occurs in the structural elements around the expansion joints is reviewed from the structural analysis.

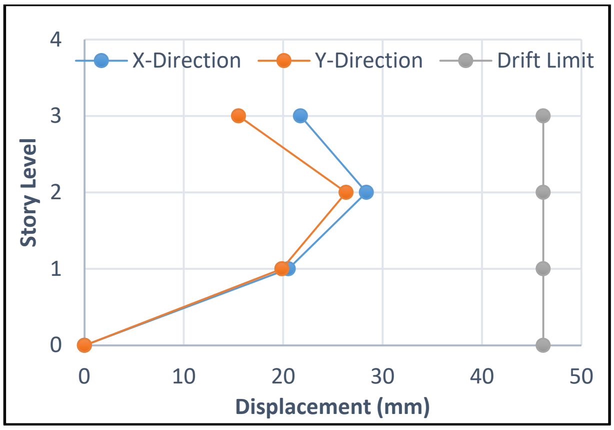

Fig. 11. Inter-story displacement of model 1

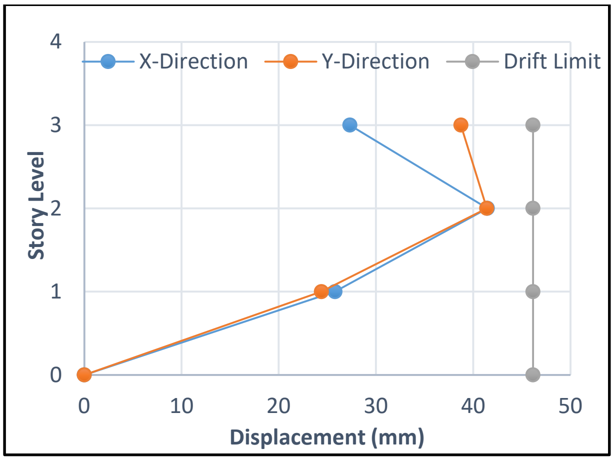

Fig. 12. Inter-story displacement of model 2

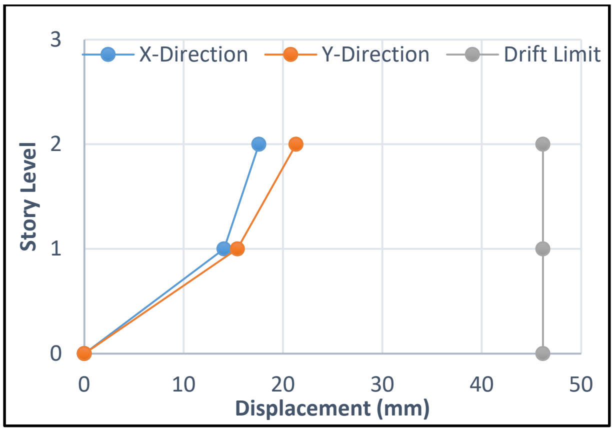

Fig. 13. Inter-story displacement of model 3

Inter-story drift, or story drift, is the difference in horizontal deflection between two adjacent building floors. It is calculated by subtracting the lower level's story displacement from the upper level's. Inter-story drift of permits is regulated in SNI 1726:2019. Inter-story drift for Models 1-3 can be seen in Figs. 11-13.

Figs. 11-13 shows that the value of X and Y displacement in each zone of the laboratory building does not exceed the permitted limits in Indonesian seismic codes (SNI 1726:2019), so the building has complied with the current seismic building codes.

3.2.3 Horizontal irregularity

In this study, horizontal irregularity is conducted to torsional irregularity in SNI 1726:2019, which requires that the limit of torsion irregularity in the direction of the horizontal axis of the structure is 1.2 and in the vertical direction of the structure is 1.4. From the results of the structural analysis of the three models, it was found that the torsional irregularity of the building still met the requirements. The results of torsional horizontal irregularity are shown in Figs. 14-16.

Overall, the results of torsional irregularity in each zone of the laboratory building have met the current Indonesian seismic building codes. Still, on the 3rd floor of zone C, there is horizontal torsion irregularity. Torsional horizontal irregularity on the 3rd floor of zone C occurs when there is an uneven distribution of mass, stiffness, or strength across its floor plan, leading to a twisting or rotational response during lateral forces such as earthquakes, as shown in Fig. 17.

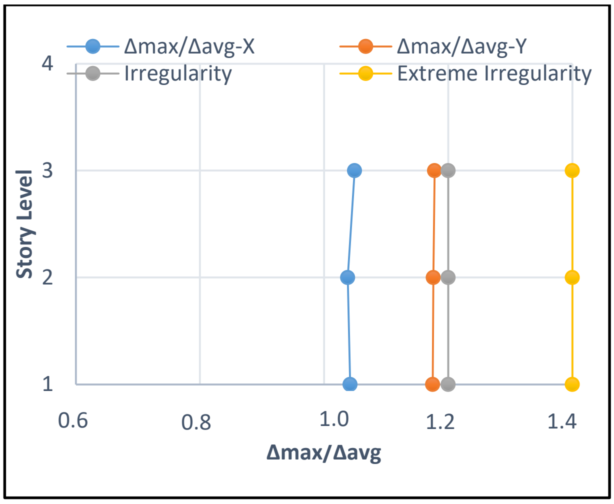

Fig. 14. Torsional irregularity of model 1 (Zone A and B)

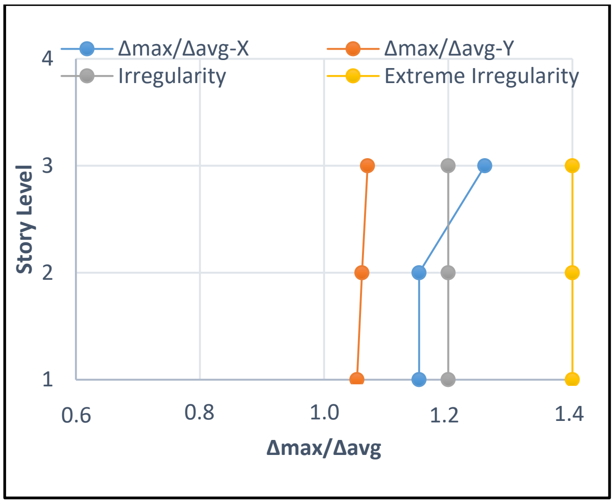

Fig. 15. Torsional irregularity of model 2 (Zone C)

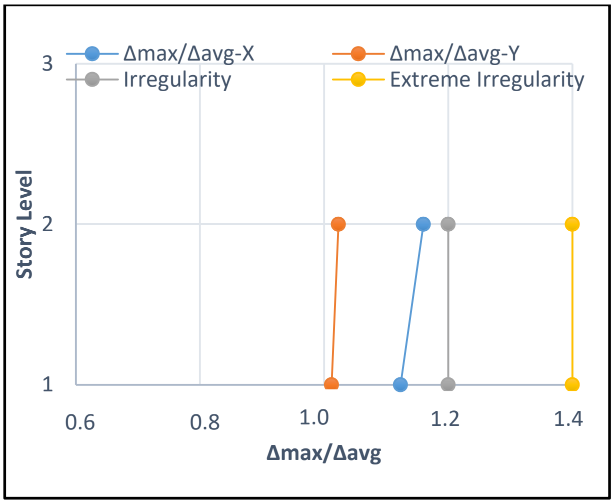

Fig. 16. Torsional irregularity of model 3 (Zone D)

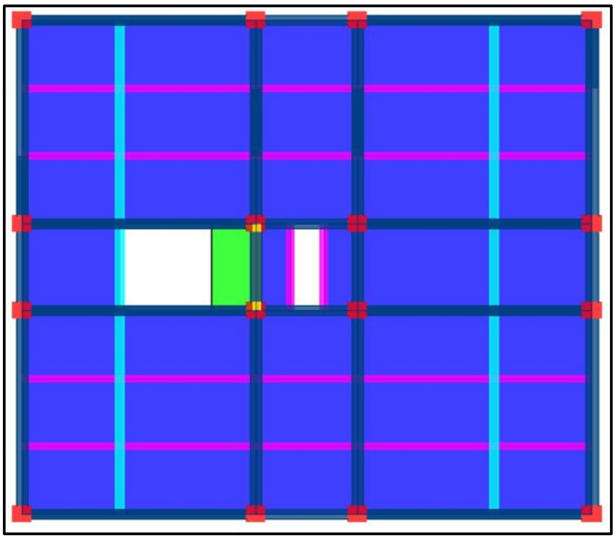

Fig. 17. Plan view of story level 3 of zone C (model 2)

3.2.4 Vertical irregularity

Vertical stiffness irregularity in SNI 1726:2019 requires that soft story stiffness irregularity is defined as existing if there is a story whose lateral stiffness is less than 70% of the lateral stiffness of the story above it or less than 80% of the average stiffness of the three stories above it, as shown in Tables 10-12. From the tables, the results of stiffness irregularity in each zone of the laboratory building have met the current Indonesian seismic codes.

Table 10. The story stiffness of model 1

Floor	X-direction		Y-direction	
	Story stiffness (kN/m)	Check	Story stiffness (kN/m)	Check
3	143337.81		141970.076	
2	364256.359	OK	351665.881	OK
1	570341.574	OK	601582.539	OK

Table 11. The story stiffness of model 2

Floor	X-direction		Y-direction	
	Story stiffness (kN/m)	Check	Story stiffness (kN/m)	Check
3	135682.15		111180.873	
2	175168.994	OK	144031.375	OK
1	452396.146	OK	553805.072	OK

Table 12. The story stiffness of model 3

Floor	X-direction		Y-direction	
	Story stiffness (kN/m)	Check	Story stiffness (kN/m)	Check
2	352534.236		363073.94	
1	636144.765	OK	605493.7	OK

4 Conclusion

The Central Laboratory Building of Universitas Andalas, located in an earthquake-prone region, was thoroughly evaluated for its seismic performance using the current Indonesian seismic codes. The evaluation results indicated that the maximum displacement in zones A, B, C, and D did not exceed the building's expansion joint distance of 50 mm, ensuring the structure is safe against pounding during an earthquake. Additionally, the building's seismic performance, including dynamic characteristics, inter-story drift, horizontal irregularity, and vertical irregularity, all complied with the relevant seismic resistance codes.

The fundamental vibration periods for the different zones met the structural planning requirements, ensuring that the building remains dynamically stable during seismic events. Inter-story drift, which measures the difference in displacement between adjacent floors, was within permissible limits, preventing excessive deformation under seismic loads. However, minor torsional irregularities were observed on the third floor of Zone C, likely caused by uneven distribution of mass or stiffness across the building's layout. Despite this, vertical stiffness irregularity checks revealed no violations, indicating uniform structural stiffness across the building's levels.

Overall, the seismic evaluation confirmed that the building complies with Indonesian seismic regulations, ensuring it is well-prepared to withstand earthquakes with minimal safety and structural integrity risk.

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